PUBLIC HEALTH IMPLICATIONS OF PCB EXPOSURES

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ABSTRACT

This paper summarizes the health implications associated with PCB exposure, primarily through the fish consumption route. Studies published in 1996 complement and continue to build upon the scientific data gathered over the last two decades which document health consequences associated with exposures to PCBs. While much of the research has been undertaken in the Great Lakes basin, the health implications are national. The findings of elevated PCB levels in human populations, together with findings of developmental deficits and neurologic problems in children whose mothers ate PCB-contaminated fish, have strong implications. The weight of evidence clearly indicates that populations continue to eat fish that contain PCBs and that there are significant health consequences associated with that fish consumption. While PCBs are declining in the environment, health concerns are still warranted.

Recent findings in human populations are discussed that indicate susceptible populations, e.g., certain ethnic groups, sport anglers, the elderly, pregnant women, children, fetuses and nursing infants continue to be exposed to PCBs via fish and wildlife consumption. Human health studies are discussed in this paper that indicate: (1) reproductive function may be disrupted by exposure to PCBs; (2) neurobehavioral and developmental deficits occur in newborns and continue through school age children who had in utero exposure to PCBs; (3) other systemic effects, e.g., self-reported liver disease and diabetes, and immune system risks may be associated with elevated serum levels of PCBs; and (4) increased cancer risks are associated with PCB exposures.

I. FINDINGS ASSOCIATED WITH PCB EXPOSURE IN HUMAN POPULATIONS

Some of the initial findings of PCBs in human populations were reported by Harold Humphrey of the Michigan Department of Public Health and his colleagues. Their work in the 70's and 80's demonstrated a correlation between levels of PCBs in fetal tissues and maternal consumption of contaminated fish (Humphrey 1983). The Michigan Maternal Infant Cohort Study (Fein et al. 1984; Jacobson et al. 1985, 1990a, b) reported both developmental disorders and cognitive deficits in the offspring of mothers who ate contaminated fish six months prior to and during pregnancy. Developmental effects included a statistically significant decrease in gestational age (by 4.9 days), birth weight (by 160 to 190 g), and head circumference (by 0.6 cm). Five months post-term these effects were still evident compared to the control population. Neurobehavioral deficits observed include depressed responsiveness throughout the course of study, impaired visual recognition, and poor short-term memory at seven months of age. At four years following birth, these deficits in weight gain, depressed responsiveness, and reduced performance on the visual recognition-memory test, one of the best validated tests for the assessment of human cognitive function, were still evident.

While these data provide a clear indication of transgenerational effects, some significant questions remain regarding causality because of recognized limitations in the studies. These include a non-random sampling technique for the selection of the study population and limited statistical power because of the size of the control group. In addition, only total PCBs were analyzed. Some of the analytical methods used in the studies, for example, the pooling of blood samples, are no longer recognized as the most appropriate analytic protocols. Moreover, numerous potential confounding factors have been identified, including exposure to other chemical contaminants and the mothers' health status at the time of the study. Nevertheless, a more recent retrospective analysis by Swain (1991) employing the epidemiologic criteria of Susser (1986), found that the relationship between PCB exposure and transplacental passage was "strongly affirmed," and the relationships between PCB exposure and developmental effects and cognitive deficits "were affirmed with reasonable certainty."

Other studies of human populations contribute to this overall weight of evidence for adverse health effects associated with exposure to PCBs. In the North Carolina Breast Milk and Formula Project, mothers had background levels of PCB exposure (Rogan and Gladen, 1985). Deficiencies in psychomotor development index were noted in children of women who had higher PCB exposures. They did not exceed test-retest differences and the effects, seen up to two years of age, were not apparent at ages 3, 4 and 5 (Gladen and Rogan, 1991). It has been proposed that neurobehavioral effects (spatial learning/memory and motor deficits) are caused by complex interactions between neuroendocrine and neurophysiological systems (Lindström et al. 1995).

Studies of PCB exposure (Harada et al. 1976; Wong and Huang, 1981; Hsu et al. 1985) via contaminated rice oil in Japan (1968) and Taiwan (1979) also contribute to the overall weight of evidence that xenobiotic agents disrupt normal endocrine function and are associated with neurobehavioral deficits. These incidents were referred to as Yusho Disease in the case of the

Japanese studies and Yucheng Disease in the case of the Taiwanese studies. Infants of exposed mothers exhibited a variety of effects including a range of neurobehavioral deficits. Cognitive testing (Bayley mental and psychomotor developmental indices, Stanford-Binet test, Wechsler Intelligence Scale for Children) showed significantly lower overall age-adjusted developmental scores in the exposed children. Delays were seen at all ages and were greater in children who were smaller in size, had neonatal signs of intoxication and/or had a history of nail deformities. Results of follow-up testing (Stanford-Binet test and Wechsler Intelligence Scale) when the children were 4-7 years old indicated that effects on cognitive development persisted for several years following exposure (Chen et al. 1992). While these neurobehavioral deficits are reminiscent of the findings of the Jacobsons, they are much more pronounced and may be due, in large part, to the presence of dibenzofurans as co-contaminants in the rice oil. The PCBs were heated in thermal heat exchangers before contamination of the rice oil occurred, and also during cooking, resulting in the production of relatively high concentrations of CDFs and polychlorinated quaterphenyl (PCQ) impurities by thermal degradation. For this reason, and based predominantly on comparisons with Japanese workers with higher PCB blood levels who had few or none of the symptoms present in the rice oil poisonings, CDFs are generally considered to be the primary causal agent. (Bandiera et al. 1984a; Kunita et al. 1984; Masuda and Yoshimura, 1984; Ryan et al. 1990; Safe 1990; Takayama et al. 1991; Tanabe et al. 1989; ATSDR, 1993).

An occupational study conducted in New York also involved exposure to PCBs (Taylor et al. 1989). The results included a decrease in gestational age and a depression of weight at birth. These results closely parallel the earlier findings reported by the Jacobsons.

Several occupational or epidemiologic studies have indicated or demonstrated other adverse health effects with exposure to PCBs. These adverse effects include cardiovascular, hepatic, immune, musculoskeletal, and cancer. Kreiss et al. (1981) have reported a 30% increase over the national average incidence of borderline and definite hypertension observed in a population from Triana, Alabama. Increased serum PCB levels were significantly associated with increased systolic and diastolic blood pressure. The relationship between serum PCB levels and systolic blood pressure disappeared when serum cholesterol and triglyceride levels were factored in, but the association between PCB and diastolic blood pressure remained significant. Consumption of contaminated fish was considered to be the dominant source of PCB exposure.

Stehr-Green et al. (1986a, 1986b) also observed increased serum cholesterol and triglyceride levels in a population who resided near a waste site for 5 years. These significantly increased levels were associated with elevated serum PCBs levels in this population. In addition, there were significant hepatic effects associated with serum PCB levels. There was a significant positive correlation of total bilirubin with serum PCB levels, and a significant negative correlation of serum albumin with serum PCB levels.

Svensson et al. (1994) assessed various parameters of immunocompetence in a group of men with

high fish consumption from the Baltic Sea. Of the various parameters assessed, e.g., white cell count, lymphocyte levels, serum immunoglobulin levels, there was a statistically significant negative correlation between the percentage of natural killer cells and weekly consumption of fatty fish (e.g. salmon).

Fischbein et al. (1979) have reported joint pain in workers who were exposed to a variety of PCB aroclors. Humphrey et al. (1983) have reported a 10% prevalence of unspecified joint problems among farm families who consumed dairy products and beef that were contaminated with PCBs.

Occupational studies have observed increases in cancer mortality in workers exposed to PCBs (Bertazzi et al. 1987; Brown 1987; Sinks et al. 1991, 1992; Yassi et al. 1994). These studies report elevated risks of malignant melanoma, gastrointestinal tract cancer, cancer of the liver, gall bladder and biliary tract cancer and cancer of the hematopoietic tissue. In addition, the nonoccupational study of Yusho victims of the rice oil poisoning (Kuratsune et al. 1988) reports significant excess cancer of the liver by the accidental consumption of up to 2 grams of PCBs in 1968. A similar incident in Yucheng, Taiwan (Hsu et al. 1985) some ten years later produced no cancer effects in these victims. This is to be expected because the latent period for cancer has not been achieved in this study.

Except for liver and biliary tract cancer, most of the findings are inconsistent across these very same studies and as such they cannot be taken as providing conclusive evidence of a causal relationship based strictly upon human evidence. On the other hand, liver and/or biliary tract cancer were found to be present, elevated or significant in several of these studies (Kuratsune et al. 1988; Brown 1987; and Bertazzi et al 1987). Epidemiologic studies that do not confirm these findings were in most part found to be incapable of demonstrating excess risks of cancer because of methodological problems inherent in the study designs i.e. insufficient latency, inadequate power, etc.

This finding of possible excess liver and/or biliary tract cancer is consistent with carcinogenic studies in animals that show excess hepatic cancer from exposure to chlorinated PCBs. Since there was little or no contamination of any of these studies from the presence of dibenzofurans except for Kuratsune et al. 1988, the possibility that exposure to PCBs is responsible for an excess risk of liver and/or biliary tract cancer in humans cannot be ruled out. Hence, because of these concerns the evidence must be regarded as suggestive although not conclusive.

II. RELEVANT STUDIES IN ANIMALS

Animal studies strongly suggest that PCB mixtures containing 60% chlorine by weight, administered via the oral route to rats, are liver carcinogens (Kimbrough et al. 1975; Norback and Weltman 1985; Schaeffer et al. 1984). Studies with Aroclor 1254 and other lower chlorinated PCBs indicate that these PCBs have weak carcinogenicity, based on lower incidences of total tumors and higher proportions of benign tumors in rats and mice (Kimbrough et al. 1972; Kimbrough and Linder 1974; NCI 1978). The International Agency for Research on Cancer and U.S. EPA have concluded that

PCBs are probable human carcinogens, based upon positive results in several well designed animal studies. (IARC, 1978; IARC, 1987; USEPA, 1996a)

Early animal studies found that high doses of highly chlorinated mixtures (like Aroclor 1260) cause liver cancer in laboratory animals. These findings contributed to the ban on manufacturing PCBs. Because, however, there was not clear evidence for lower chlorinated mixtures (like Aroclor 1242), there has been controversy about whether other mixtures cause cancer.

A 1996 study (Brunner et al., 1996, recently released to USEPA) appears to have settled this matter. This study tested Aroclors 1260, 1254, 1242, and 1016 and found that each mixture causes liver tumors in female rats. Thyroid cancer was found in male rats. Together, these commercial mixtures span the range of congeners most often found in environmental mixtures. To date, the final report has not been published.

The 1996 rat study found higher cancer risks for Aroclors 1260, 1254, and 1242 than for 1016, suggesting that the cancer risk may be mostly attributable to some highly chlorinated congeners. New studies of the mechanisms that cause cancer show that PCBs promote liver and lung tumors; these studies are beginning to identify specific congeners that may significantly contribute to cancer induction. As with other risk assessments, using high-dose animal studies to make inferences about human environmental exposure can involve considerable uncertainty. The inconclusive nature of the human studies reinforces this uncertainty.

In 1996 EPA reassessed the cancer risk of PCBs (USEPA 1996b), considering the new cancer study along with information on how health risks are increased or decreased by the environmental processes of partitioning, chemical transformation, and preferential bioaccumulation. Partitioning refers to different fractions of a mixture separating into air, water, sediment, and soil. Chemical transformation occurs through biodegradation in the environment. Preferential bioaccumulation through the food chain tends to concentrate highly chlorinated congeners, which are often among the most toxic and persistent.

In EPA's 1996 reassessment of PCB cancer risks using the 1996 rat data, upper bound cancer slope factors were compared with central estimates. The use of usual upper bound values was found to increase cancer slope factor estimates by only two fold.

Bioaccumulation makes PCBs in fish especially hazardous to humans. Some PCBs persist in the body and retain biological activity after exposure stops. Bioaccumulated PCBs appear to be more toxic than commercial PCBs and appear to be more persistent in the body. For exposure through the food chain, risks can be higher than for other exposures.

III. RECENT RESEARCH FINDINGS FROM HUMAN HEALTH STUDIES IN THE GREAT LAKES BASIN

In 1990, Congress amended the Great Lakes Critical Program Act, stipulating that the U.S. EPA, in consultation with ATSDR and the Great Lakes States, submit to Congress a research report assessing the potential health effects of water pollutants in the Great Lakes basin. To date Congress has appropriated $12 million to support human health effect studies. While significant research remains to be completed, initial findings of the ATSDR's Great Lakes Human Health Effects Research Program (GLHHERP) are now available.

ATSDR's GLHHERP is designed to investigate and characterize the association between the consumption of contaminated Great Lakes fish and short- and long-term harmful health effects. Several human populations have been identified who have a potentially higher risk of short- and long-term health effects because of their elevated exposure to and or physiologic sensitivity to contaminants in Great Lakes fish. These susceptible populations include sport anglers, Native Americans, women of child-bearing age, pregnant women, fetuses and nursing infants of mothers who consume contaminated Great Lakes fish, infants and children, the elderly, and the urban poor. The ATSDR Great Lakes Research Program has focussed its research efforts on these populations in the Great Lakes basin.

The ATSDR Great Lakes Research Program is in its fourth year of a comprehensive research program administered through the award of grants to state health departments and academic institutions in the Great Lakes basin. Research findings in the areas of exposure, health effects, and sociodemographics of recent human health studies have been peer reviewed and are outlined below.

Exposure

Several ATSDR-funded epidemiologic studies document exposure of susceptible populations to various persistent toxic substances (USEPA 1995; Dellinger et al. 1995, 1996; Fitzgerald et al. 1996; Lonky et al. 1996; and Schantz et al. 1996) identified by the International Joint Commission (IJC 1983). Fitzgerald et al. (1996) are studying a population of Native Americans to investigate the association between the consumption of locally caught fish and wildlife and body burdens of PCBs (68 congeners), dichlorodiphenyl-dichloroethylene (DDE), mirex, and hexachlorobenzene (HCB). Preliminary data from this study indicate that Native American men are more likely than women to consume local fish, and they ate at least 8 fish meals per month for at least two years before participating in this study. The mean PCB concentration in these men was 5.4 parts per billion (ppb) which is higher than a general population value of 2 ppb published by Jensen (1987). The maximum PCB serum value reported was 31.7 ppb. This study also demonstrated that (a) serum PCB concentrations were positively related to the number of fish meals consumed per year, and (b) serum PCB concentrations in men increased with age.

Schantz et al. (1996) are studying an elderly population of sport anglers, 50-90 years of age. This population consisted of two groups: (a) high fisheaters who have been consuming 24 pounds or more of Great Lakes sport-caught fish annually for more than 15 years, and (b) low [or nonfisheaters] who consumed less than 6 pounds annually. This study demonstrated that median levels of total

PCBs, DDE, and mercury were significantly higher in high fisheaters than in low fisheaters. The median serum total PCB concentration for high fisheaters was 12 ppb and 5 ppb for low fisheaters; the maximum values were 75 ppb and 26 ppb, respectively. The median serum DDE concentration for high fisheaters was10 ppb and 5 ppb for low fisheaters; maximum values were 145 ppb and 33 ppb, respectively. The median mercury level in high fisheaters was above that of low fisheaters, 2 ppb versus 0 ppb; the maximum values were 21 ppb and 5 ppb, respectively. Additionally, high fisheaters presented disproportionately higher body burden levels of PCBs and DDE than low fisheaters in each age group; i.e., 50-59, 60-69.

Lonky et al. (1996) are investigating pregnant women and the effects of maternal exposure to Great Lakes contaminants on their newborns. Women in the high fish consumption group reported eating an average of 388 PCB- equivalent pounds of Lake Ontario fish over 16 years, which is equivalent to approximately 2 pounds of salmon or lake trout per month with belly fat trimmed and skin removed (about 30 g/day)

Waller et al. (1996) are conducting a similar investigation with African-American women and their newborns. The preliminary data from this research also indicate women continue to consume Great Lakes fish during most of their reproductive years. Seventy-five percent of the women in the study are less than 26 years of age and reported consuming lake fish for more than 15 years.

One thousand nine hundred fifty questionnaires or survey instruments have been collected and analyzed in an ongoing study in Michigan of reproductive age (18-34) men and women sport anglers (Courval et al. 1996). These data indicate approximately 50% of this population have eaten 1-12 sport-caught meals in the past year, and 20% consumed 13-24 meals per year. Fish consumption was greater in males than females with some males consuming 49 or more fish meals per year. Two hundred and eighty-seven eligible couples (those couples with no identified impairments to reproduction) were identified from this group. These eligible couples also intend to have one or more children in the next five years. PCB levels are currently being determined in these couples to assess the effects of PCB exposure on reproductive function.

West (1993) surveyed 2,451 State of Michigan licensed anglers who were fish consumers out of a total population of 368,557. Analysis of the data base indicates that a projected 11,900 sport fishers eat a meal per week or more of coho, chinook, and unidentified non-commercial salmon. (Jacobs 1995).

Studies have also been undertaken that investigate the role of various environmental pathways of exposure to Great Lakes contaminants. Earlier multimedia studies by Birmingham et al. (1989) and Newhook (1988) indicated that the majority (80-90%) of human exposure to chlorinated organic compounds comes from the food pathway. A more recent multimedia study supports these findings and indicates the major pathway of exposure to persistent toxic substances, e.g., PCBs, is via fish consumption (Fitzgerald et al. 1996.)

PCBs are considered the dominant organochlorine residue in fish from the Great Lakes (Michigan Department of Environmental Quality, 1996). Using risk assessment values then available and several consumption assumptions, Dourson and Clark (1990) deduced that PCBs would contribute the majority of the non-cancer risks from Great Lakes fish consumption, although organochlorine pesticides could contribute some to the overall risk.

Health Effects

Recent studies indicate exposure to Great Lakes contaminants may cause disturbances in reproductive parameters and demonstrate neurobehavioral and developmental deficits in newborns and older children.

Courval et al. (1996), in their study of reproductive age men and women in angler households, hope to study the conception rate and the incidence of a live birth among women who are fish consumers. Prior pregnancy rates among women of the eligible couples (those intending to have children) were lower compared with all women in the study, 55% versus 72%, respectively. Additionally, 45% of women of eligible couples had had a live birth compared with 64% of all women in the study. No information is given yet on general population or nonconsumer conception and live birth rates; 80% of both groups are fish eaters at the outset of the study.

Reproductive function may be disrupted by exposure to PCBs. Female rhesus monkeys exposed to PCBs have alterations in menstrual cycles (e.g., duration and bleeding), decreases in fertility, increased abortions and reductions in the number of conceptions (Barsotti et al, 1976, Arnold et al., 1990).

Lonky et al. (1996), investigating pregnant women and the effects of maternal exposure to Lake Ontario contaminants on their newborns, found in utero exposure results associated with neurobehavioral deficits which can be assessed shortly after birth. Five hundred and thirty-six newborns of women who consumed a PCB-indexed amount of fish in a lifetime either:

(a) of at least 40 pounds (high exposure), or
(b) of less than 40 pounds (low exposure), or
© who had consumed no Lake Ontario fish (controls)

were examined using the Neonatal Behavioral Assessment Scale (NBAS) 12-24 hours after birth and again at 25-48 hours after birth. Newborns of high exposure mothers exhibited:

- a greater number of abnormal reflexes;
- less mature autonomic responses; and
- less attention to visual and auditory stimuli

in comparison to newborns of low- or no exposure mothers, after adjustment for a variety of potentially confounding factors. These results indicate that despite moderate levels of salmon or lake trout fish consumption (about 30 g/day), newborns of mothers from the high exposure group scored more poorly on the NBAS than those newborns from the low exposure or control group.

These results represent the first replication and extension of the neonatal results of the Lake Michigan Maternal Infant Cohort study by Jacobson et al. (1984). The Lake Michigan Maternal Infant Cohort study was the first epidemiologic study to demonstrate an association between the amounts of Lake Michigan fish reported consumed by mothers and behavioral changes in their newborns assessed by the NBAS. Two hundred and forty-two infants born to mothers consuming the greatest amount of contaminated fish showed: (1) more abnormally weak reflexes; (2) greater motor immaturity and more startles; and (3) less responsiveness to stimulation.

A recent re-examination of 212 children from the Lake Michigan Maternal Infant Cohort Study indicated neurodevelopmental deficits assessed in infancy and early childhood still persist at age 11 (Jacobson and Jacobson 1996). These children were exposed in utero through mothers who consumed fish six months prior to and during pregnancy. After adjustment for a variety of potentially confounding factors, the study results indicated the most highly exposed children (based on maternal milk PCB concentration):

- were three times as likely to have low full scale and verbal IQ scores;
- were twice as likely to lag at least two years in reading comprehension; and
- have difficulty paying attention.

These intellectual impairments are attributed to in utero exposure to polychlorinated biphenyls and to related contaminants at concentrations slightly higher than those found in the general population. How the presence of lead and mercury relate to PCBs levels in the same children is not clarified, but impairment is also associated with higher concentrations of these other substances.

As evaluated by Tilson et al. (1990) the neurobehavioral effects observed in children exposed to PCBs have also been found in rhesus monkey studies. Bowman et al. (1978), Bowman and Heironimus (1981), Mele et al. (1986) reported decreased performance in discriminating learning tasks at six and twelve months of age in offspring of female monkeys exposed to Aroclor 1248. The degree of impairment was related to levels of PCB in body fat similar to findings found in the Jacobson studies. The same monkeys tested at 44 months of age were hypoactive relative to controls. Levin et al. (1988) reported neurobehavioral deficits in the young of monkeys fed Aroclor 1248. Schantz et al. (1989) reported deficits in spatial discrimination of infant monkeys whose mothers were exposed to Aroclor 1016.

Although their data have not been peer reviewed, Dellinger and Hegman (Written communication,

June 7, 1996) have recently reported preliminary findings from Native Americans (Ojibwa) that consume Great Lakes fish. In a review of 101 participants to date, elevated PCB serum concentrations were correlated with self-reported diabetes and liver disease. This correlation confirms similar findings of these investigators in the Red Cliff Band of Lake Superior Chippewa (1990-1993). In another ongoing study of Native Americans, Fitzgerald et al. (Written communication, June 6, 1996) are examining the activity of selected liver enzymes in Mohawk men and women at Akwesasne. Induction of these enzymes is among the earliest and most sensitive response to coplanar PCB congeners. To date, the test has been performed successfully on 45 women and 38 men. The results of these studies are currently being evaluated and interpreted. Because many Indian populations have a high incidence of diabetes and/or liver problems whether or not PCBs are involved, peer review will help to put these data in perspective.

Sociodemographics

Studies of susceptible populations in the Great Lakes basin indicate a wide variation in social behaviors. For example, knowledge of and adherence to health advisories for sport-caught fish varies across different populations, and fish is an essential component of the diets of certain local minority populations and Native Americans; they also consume fish that have higher levels of contaminants. An epidemiologic study investigating Native American men found 97% of the men knew about the advisories regarding consuming local fish (Fitzgerald et al. 1996).

Waller et al. (1996) indicated that knowledge of fish advisories in minority populations may be low; and these populations tend to consume fish that have higher levels of contaminants, i.e., catfish and buffalo.

The survey conducted by West (1993) found that the general population had considerable knowledge of fish advisories. Seventy-one percent of licensed anglers (based on 10% of all respondents) changed species consumed from the Great Lakes, as a result of fish advisories. Sixty-five percent removed the skin, with the response rate being very similar for Native Americans, African Americans, and whites. While forty-nine percent of anglers followed fat trimming recommendations, African Americans had the lowest rate (26%) of fat trimming. Only thirty-three percent of the general population broiled, grilled or baked fish as recommended by fish advisories, with lower percentages reported for Native Americans and African Americans.

Summary

In summary, the recent research findings from human health studies in the Great Lakes basin indicate:

- Susceptible populations are being exposed to PCBs via fish consumption;
- Many individuals in the Great Lakes consumed more fish than the 6.5 g/day often estimated for the general population;

- High consumption of PCB-contaminated Great Lakes fish is associated with increased body burden levels of PCBs;

- These body burden levels are higher than in the general population;

- Men consume more fish than women; men and women eat Great Lakes fish during most of their reproductive years;

- Neurobehavioral and developmental deficits occur in newborns and continue through school age in children exposed in utero to PCBs. Some observed results have also been associated with heavy metals (e.g., mercury, lead);

- Current fish intake rates and derived PCB exposures for some persons are similar to those found associated with adverse health effects in children in epidemiological studies;

- Reproductive function may be disrupted by exposure to PCBs;

- Adult men, women beyond reproductive years, and the elderly are at an increased risk of cancer, and may also be at an increased risk of immune and endocrine system effects, from exposure to PCBs in fish;.

- Although PCBs dominate the projected risks from the consumption of Great Lakes fish, organochlorine pesticides, mercury, dioxin and dibenzofurans are among compounds that contribute to the overall risk.

While the research findings discussed in this section are preliminary, they have strong implications when viewed together with earlier findings. Data for over 10,000 at-risk individuals are presently being collected, analyzed, and interpreted. Initial research findings on body burdens and health effects support earlier reports of an association between the consumption of contaminated Great Lakes fish and body burdens of persistent toxic substances. These body burdens, reflecting exposures to a variety of persistent substances such as PCBs and organochlorine pesticides, are three- to four-fold higher in some groups than those in the general population; research studies are ongoing to assess other potential effects of these contaminants on human health.

IV.. EXPOSURE INTERPRETATION

Exposures as derived or measured for use in epidemiologic analyses do not always correspond to the units in which people consume fish or other foods. Some calculations have been undertaken to provide a perspective on the quantities identified in two studies discussed by this paper.

Fish consumption estimates based on the 1991-1992 Michigan Sport Anglers Fish Consumption Survey provide estimated proportions who eat various Great Lakes fish among a population of 368,557 licensed State of Michigan anglers based on a sample of 2,451. Diaries were used to estimate amounts consumed by self-declared fish eaters of noncommercial or sport fish. The means (and 95th percentiles) for weekly salmon consumers were 35.6 (40.0) g/day for chinook, 41.6 (74.8) g/day for coho, and 42.6 (86.5) g/day for unidentified non-commercial salmon species.

Lake Michigan coho salmon (23") currently average 0.75 ppm total PCBs and chinook salmon (28") average 1.1 ppm total PCBs (1995 Fish Contaminant Monitoring Annual Report, Michigan Department of Environmental Quality, 1996). If cleaning and cooking reduce PCB levels in fish by 50%[1], daily PCB intakes for this population consuming Lake Michigan fish would range from an average 15 µg PCB/day (weekly coho salmon consumption) to 40 µg PCB/day at the 95th percentile consuming unidentified non-commercial salmon species. For a 60 kg woman, corresponding daily intake would range from 2.5 E-4 to 6.7 E-4 mg PCB/kg-day. West et al. (1993) have reported as much as 50-60% of this angler population observe cautions to trim skin and belly fat and about 30% to broil, grill or bake the fish.

By comparison, the State of Minnesota (Shubat, 1990) estimated a PCB intake of 30.5 µg PCB/day for those women in the Jacobson et al. (1984, 1985, 1990) study where children experienced neurological effects. For the women (average weight 62 kg) evaluated, it estimated the average daily PCB dosage associated with adverse health effects (when fish were assumed to be the only PCB source) was 4.9 E-4 mg PCB/kg-day. Prior to selection, the subjects of the Jacobson et al. study, whose consumption amounts and species are based on recall of an average of 16.1 years (range 1-40) prior to study, reported consuming the equivalent of an average 6.7 PCB-kg/year (standard deviation 5.8; range 1.2-41.7 PCB-kg), based on assuming 0.2 kg fish consumed each meal, the highest annual rate of consumption, and a cumulative rate during pregnancy. PCB concentrations for Jacobson's derivations in 1984 were based on data of Humphrey (1976).

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[1] Studies on skin removal and fish trimming indicate PCB and DDT can be reduced about 50% (Reinert, et al., 1972; Skea, et al., 1979; Voiland, et al., 1991). PCB reductions owing to cooking are more variable (Zabik 1979, 1993). A Great Lakes States Task Force has recommended considering an overall 50% single lipophilic contaminant reduction from preparation and cooking to be a realistic expectation for salmon and lake trout (Anderson et al. 1993).

During the year prior to pregnancy, the women were calculated to have consumed 4.4 PCB-kg (standard deviation 4.4; range 0.0-26.5 PCB-kg).

Amounts in the Lonky et al. (1996) study were assessed just prior to or at the onset of pregnancy. High-exposure subjects consumed on average about 30 g/day of Lake Ontario fish and PCB-equivalents were calculated indexed to various species and trimming and cooking behavior. In 1991, Lake Ontario coho and chinook salmon averaged 1.6 ppm total PCBs. In 1989, lake trout averaged 2.5 ppm (Forti, 1996). With the same 50% reduction in levels used above with the West et al. (1993) data, the high-exposure group could be deduced to have had an estimated daily exposure of about 32μg PCB/day (or an average daily intake of 4.5 E-4 mg PCB/kg-day for the 70-kg women in the high-exposure group) if it is assumed that salmon and trout are eaten equally.

Thus, despite a variety of sources of uncertainty in the Jacobson et al. (1996) and the Lonky et al. (1996) studies and in estimations of PCB exposures, the derived maternal PCB intakes associated with developmental effects are very similar. Moreover, consumption of some fish (e.g., salmon) reported in the West et al. (1993) consumption survey also yields PCB intakes similar to those estimated from the Jacobson and Lonky studies.

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